THE ELECTRIC CAR AND THE PETROLEUM CHEMICAL INDUSTRY:

BOON OR BANE?
TREAT OR THREAT?

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Petroleum Chemical Industry Conference
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SUMMARY

The all-electric automobile is still a long way off, unless an unexpectedly energetic battery or fuel cell is being hidden in a laboratory someplace. Batteries and similar devices available today will not propel a vehicle far enough nor fast enough between recharges, for most uses.

For certain special applications, such as short-haul buses, delivery vans and taxis in highly congested urban areas, the all-electric is possible. These types would represent such a small percentage of the automotive vehicles being used in the United States, that they would not represent any serious inroads into the use of petroleum chemical products for heat engine motive power applications.

The heat engine/battery hybrid, a battery powered vehicle, with a small petroleum fueled heat engine aboard that drives a generator, which in turn charges the batteries, is a new contender in the "low emission vehicle sweepstakes". This hybrid avoids the problem of short range of electric vehicles, and reduces vehicle emissions noticeably. It will allow for the gradual evolution from the all-heat engine to the all-electric drive, whether it be over a period of the next 2 decades or 5 decades, with minimum disruption of the petroleum chemical industry, the automobile industry and the electric power industry. A successful heat engine/battery hybrid will prove a boon to the petroleum chemical industry, as demands for other than automotive power applications take a larger percentage of the available fossil fuels.

INTRODUCTION

The enormous interest in electric automobiles is occasioned mainly by the increasing problem of air pollution throughout the country, particularly in congested urban areas.

Of many authoritative reports, the one by H.E.W. (1) indicates that of the entire air pollution in the country, 60% is contributed by internal combustion engine vehicles. In some congested urban areas, the pollution at ground level may be as much as 85% due to automotive vehicles of all types, cars, buses, taxis trucks, etc.

Despite the expended efforts on the part of the automobile industry, the petroleum chemical industry and the government to "clean up" the internal combustion engine, there has been little dramatically evident progress. So, the public remains skeptical about a pollution-free internal combustion engine car being developed by "Detroit". The vehicles' exhausts still smell, the engines and exhausts still make noise, and frequently the exhaust is smoky. The increasing number of vehicles offsets to a degree the decrease in emissions from individual vehicles that are the result of techniques introduced in the last decade for emission reduction on cars.

The "no emission" electric vehicle is obviously infinitely better than any internal or external combustion engine, with respect to pollutants from the vehicle itself. No matter how well cleaned up the heat engine may be, at best it results in a "low emission" vehicle. So, from an emission point of view alone, the electric is attractive.

Note that the term "no pollution" has not been employed. It is recognized that some place or other the electric power must be developed for ultimate use in the vehicle. However, it is further recognized that it is much easier to control a few smoke stacks from fossil fuel burning electric power generating plants, than to control the emissions and pollution from millions of vehicles' tail pipes. Certain pollutants associated with heat engines, such as carbon monoxide and unburned hydrocarbons, are either non-existent in, or constitute a negligible part of, the effluents from the smoke stacks of an electric power station. Therefore, the term "no emission" is more descriptive and technically accurate.

The second reason for the search for a better battery is the recognition that ultimately the fossil fuels buried in Mother Earth will be depleted, and those precious resources will be required for other aspects of our advanced civilization.

THE BATTERY PROBLEM

The basic problem with the battery is that the amount of energy per pound is, with modern low cost batteries, significantly lower than that of gasoline. This has been pointed out by many, and Wouk (2) has "quantized" the problem as shown in Table I.

TABLE I

Comparison of Energy Densities, Batteries versus Gasoline

Energy Source	W Hr/lb (approx)
Common Batteries in Use	10
Exotic Batteries Extant or Being Developed	100
Gasoline	1000

It can be seen that common batteries have 10 watt hours per pound, whereas a gasoline engine can be considered to have 1000 watt hours per pound. This means that if a tankful of gasoline will drive a car 300 miles at 60 mph, a "tankful of batteries" will drive a car only 3 miles, under the same conditions.

If there were no hope for better batteries, work on a viable electric automobile would be futile. However, competent authorities have indicated that the electrochemical reaction can provide substantially higher energy densities than the common lead acid, or the much more costly nickel cadmium batteries. This is shown

in Table I, under the heading "Exotic Batteries Developed or Extant", where energy densities as high as 100 watt hours per pound have been achieved in the laboratories.

This is still far from spectacular, resulting in a range of 30 miles, in the example given above.

However, for certain limited applications, one need not go 60 miles an hour; in congested urban areas an average speed of 30 miles an hour is acceptable. Because of the lower energy expenditure per mile at the lower speed, one might achieve operation for almost 100 miles before batteries need to be recharged, with 100 Wh/lb. The batteries could then be recharged overnight, thus pleasing everybody, as the electric power demand would come at night, when total electric power loads are well below peak generating capacities.(3).

OBJECTIONS TO BATTERY POWERED VEHICLES.

Putting aside the frequently aired, but nevertheless wrong, commercial objections to electric automobiles, (i.e., all garage mechanics will be put out of work because there won't be anything to repair; gasoline service stations will have to close down, because no one will buy gasoline...all of which is not correct) there are two technical objections which deserve consideration. Both objections are not valid, but should be mentioned.

a. Where will all the electric power come from to charge the batteries to drive electric vehicles?

b. What about the generating stations that generate the electric power? Don't they also pollute the air? Therefore, we are merely exchanging one type of air pollution for another.

Both of the above are incorrect, because of the following:

a. Excessive electric power:

Various methods have been used to estimate the increase in electric power if all automotive vehicles were converted to electric vehicles overnight. These range from the wild, undocumented figures of 100 times the present capacity (4), to the more realistic figures of doubling of the total power. This has been shown by Wouk (5), and many others. Typical calculations are shown in Appendix A. Since electric vehicles will be introduced over several decades, increased generating capacity will be designed into the electric power generating plants that will be built to provide the normal increase in electrical power consumption.

Further, much battery recharging will be done at night, when electric power generating plants are operating well below their maximum capacities. Therefore, a major part of the electric automobile recharging load will be off-peak, and welcomed "fill-in" load for the electric utilities (3).

b. Electrical power as a pollutant.

This objection is correct in principle, but is erroneous in degree.

First, it is obvious that it is possible to control the effluents from several dozen smoke stacks in a city, much easier than it is to control several hundreds of thousands, or a million tail pipes from heat-engine vehicles in the same area. Beside being easier to supervise, smoke stacks are easier to design physically to cut the effluents down to as low a value as desired.

However, what is more important is the fact that the effluent from the smoke stack of a fossil fuel burning power generating station is inherently much less polluting than the effluents from an internal combustion engine. Table II, adopted from Cozzens (6), shows the comparison.

TABLE II

Type of Pollutant	Automobile	Fossil Fuel Generating Station
Carbon Monoxide	1	0
Carbon Dioxide	1	1
Unburned Hydrocarbons	1	0
Oxides of Nitrogen	1	1/6
Sulphur Oxides	0.05	1

(NOTE: The quantities are not shown in absolute total values).

It can be seen from this table that the most noxious of all the effluents, carbon monoxide, does not exist in fossil fuel stations. The most obnoxious, unburned hydrocarbons, also does not exist in the fossil fuel stations. Therefore, those pollutants which do exist, not only are lower in total amount, but are lower in specific noxious effects. The dilution effect of smoke stacks' discharge high in the atmosphere frequently is also helpful. Sulphur oxides can be reduced by fuel control and "scrubbing".

Left out of the above discussions is the possibility of substantial increase in the output of nuclear power stations. If nuclear electric power generating stations are allowed to expand in percentage, then the problems of air polluting effluents are reduced. It is assumed that the problems associated with minimizing the hazards of accidental contamination of the atmosphere and the surrounding area by radio active materials, have been properly accounted for, along with disposal of radioactive wastes.

Further, it is assumed that the new "bandwagon" of thermal pollution will also have been properly controlled.

If we look to the very distant future, and the hopeful success of fusion power, then the problems of radioactivity are eliminated, and only the problem of thermal pollution (if any) remains.

HEAT ENGINE/BATTERY HYBRID

With the heat engine vehicle being a continuous source of pollution irritation in the foreseeable future, and the all-battery vehicle not being viable in the immediate future, is there any hope for a viable low emission vehicle with today's technology? If so, how does it affect the petroleum chemical industry?

The answer is "yes", with the heat engine/battery hybrid, a low emission vehicle is possible with present technology. In this well established concept, a small heat engine is on the vehicle, the heat engine driving an electric generator that replaces the energy drawn from the batteries during driving and acceleration. This is shown schematically in Fig.1.

The factors that enable the air pollution level to be so low are:

a. When the vehicle is operating on batteries alone, there are no vehicle emissions.

b. When the engine-generator set is operating, it operates at optimum tuning, so that the emissions are at the lowest level possible, consistent with the load requirements.

c. The three main "culprits" in producing high amounts of emissions per mile in an ordinary internal combustion engine are eliminated completely. These are:

1. Idling (an electric motor does not "idle").

2. Acceleration (the engine in the hybrid never is called upon to assume a heavy load in a short period of time).

3. Rapid deceleration from high speed (the engine can go from full throttle to zero throttle, with no forcing of unburned fuel through the system due to engine high speed. The engine has only its own inertia to contend with in slowing down, not the inertia of the entire automobile).

Therefore, the average emission includes the average over that length of time when there is zero emission, and that length of time when the emission level is low to begin with. The average of emission per mile can therefore be well within the low levels established for 1975 cars.

Why are there not vehicles being built at present in the hybrid design? As pointed out (7), the question is one of initial cost. Before the question of costs is discussed in detail, it

is best to compare the basic concepts of a conventional automobile and an all-electric to the hybrid.

To review briefly, Fig. 2ashows the basic operation of a vehicle employing internal combustion engines. The gasoline tank serves as the storage of the energy, in the form of chemical energy which will drive the vehicle.

The internal combustion engine converts the potential chemical energy into mechanical power. Unfortunately, for clean air, the internal combustion engine is inherently a very high emission device. Hence, the enormous pressure for alternatives to the internal combustion engine, to operate a vehicle with substantially reduced emissions.

The clutch is mandatory because of the fact that the internal combustion engine, (except for extremely minor applications not relevant to vehicles such as automobiles), cannot be started under load. Therefore, the engine must somehow or other be removed at start from the driving wheels. Originally there was a mechanical clutch; today the fluid clutch is popular.

The gears are mandatory because the internal combustion engine will not operate properly (except, again, for the very limited, non-relevant applications over very wide ranges of speed and load). Therefore, on Fig. 2a, the "speed control" is indicated as consisting of the gears, the clutch, and, to some degree, the internal combustion engine.

On the same drawing, at the bottom, is shown the substantially simpler system of the electric vehicle. The stored energy is in the battery, in the form of chemical and electro-chemical processes.

The speed control consists of high power electronic devices, usually semiconductors, that allow the stored energy of the battery to flow into the motor at the rate corresponding to the requirements depending upon terrain, load, acceleration, desired speed, etc.(5). When properly designed, no clutch or gears are necessary. The electrical energy is converted to mechanical power in the electric motor, which, in turn, drives the wheels.

The attractive simplicity of the electric vehicle was effective during the early part of the 20th. century, when electric vehicles were driven by "Our Great Aunt Matilda". The vehicle could not go very far, nor very fast, but this was not necessary, because the vehicle was used only for local shopping and visiting other ladies for tea. The time required to recharge, many hours overnight, was not bothersome. In addition, the roads that would have enabled people to go very far and/or fast, had not as yet been built, so that the electric car was practical.

The invention of the self-starter dealt a death blow to the electric vehicle, because now anybody could use an internal combustion engine automobile, (assuming one could learn the coordination of clutch and gears, a requirement which was completely

eliminated by the automatic transmission).

Now examine Fig.1, the basics of the heat engine/battery hybrid, (which we will occasionally shorten to HEBAH.) Again, we have a fuel tank with the stored energy in the form of gasoline, diesel fuel, kerosene, etc. Now the device that converts chemical energy to mechanical power can be either the internal combustion engine, with a substantially reduced average emission rate, (for reasons discussed below) or the external combustion, such as a turbine, a steam device, etc. Those problems that prevent the successful development of external combustion engines, such as steam engines and gas or steam turbines, revolving usually around the varying load applied in automotive applications, do not apply here.

The "prime mover", "the heat engine", then operates a device which will produce direct current power for charging the battery or driving the vehicle, or both. This can be either a dc generator or an alternator and rectifier.

Then we also have the battery, which represents a source of stored energy, and the electrical energy from the generator either flows to the wheels, and/or flows into the battery, or does not flow at all. When the internal combustion engine is not operating, then the battery provides all of the power to the next item, the electronic circuit speed control, and from thence to the motor and to the wheels.

It is the additional complexity of the hybrid which hitherto has prevented it from being looked at as an immediate help to reduction of emissions from vehicles. The motor and electronics of Fig.1 must be of the same size as that of an all-electric in order to have equal vehicle performance. So, no economics can be effected here.

<u>However</u>, the battery of Fig.1 can be much smaller than that of Fig. 2b, and the engine of Fig. 1 can be much smaller than the engine of Fig. 2a. Substantial cost savings apply here. The gasoline tank can be as large as desired, and this overcomes completely the objection to the all-electric vehicle, i.e., the necessity of having to recharge the batteries too frequently for long distance trips, and possibly even for urban use.

Two major factors contribute to the substantially lower average emissions of the "prime mover" <u>even</u> when it is operating:

1. The engine of the hybrid can be a substantially smaller engine than that of Fig. 2a, because it need not provide the <u>peak</u> power required for acceleration, climbing hills, etc. The battery in the hybrid can provide all the peak power necessary. The engine need provide only the <u>average</u> power consumed, which, even at 50 miles per hour for a vehicle weighing 4000 pounds, is only 100 horsepower.

2. As mentioned above, when the engine is operating, it is operating at its lowest specific emission.

The above factors, when combined, make conservative estimates of the average emissions to be as low as 1/8 that of present day vehicles, or as high as 1/4. But, because of the complexity, the initial cost of the HEBAH vehicle for equal performance, tended to be, on analysis, noticeably higher than the equivalent "pure internal combustion engine", which is quite "impure" with regard to emissions.

All of the auxiliaries currently associated with the type of car desired by the American public, could now be incorporated into the HEBAH vehicle. These include air-conditioning, power steering, power brakes, etc. As a matter of fact, some of these auxiliaries would perform in a superior manner, because they would now be electrically driven from a fixed voltage source of power. The air conditioning, for example, today requires an over-sized internal combustion engine. Among other reasons is the fact that the compressor of the air-conditioner must operate over such a wide range of speeds, because car occupants want air-conditioning when the engine is idling, as well as when the car is moving. With the hybrid, the compressor could be driven by a comparatively small high-frequency electric motor, operating from electronic equipment that would convert the dc from the battery to high-frequency ac.

Similarly, heating for the vehicle could be electric and operate instantaneously. Even in the coldest weather, the car could be warmed up as soon as the switch is turned on, by power from the battery. Starting the engine in cold weather would be no problem. The vehicle would start up as an electric, and while it was moving, the full power of the batteries would be available for starting the heat engine. Also, power could be available from the batteries to warm the engine prior to starting, thus making it simpler to start.

The hosts of other advantages of the HEBAH are too great to list here. Many of them have been covered by Hoffman, (7).

THE FUTURE OUTLOOK

What about the future?

If the heat engine/battery hybrid is the best that is ever to be hoped for, then there might be questions about proceeding too far with the development thereof. Eventually, the increase in the motor vehicle population would "catch up with the present automobile pollution levels". However, the HEBAH is an ideal transition vehicle for the next decades, until the all-electric is made viable, first with a battery energy density of 100 watt hours per pound, then 200 and then 300. A level of 1000 watt hours per pound will eliminate even the requirement of rapid charge capability for any application except the occasional long distance trip of over 200 miles. A battery of 1000 watt hours per pound will take a car over 300 miles between recharges.

Hoffman (7) has indicated how the reliance on the fuel tank will decrease, and how the "no emission" electric drive will take over more and more of the hybrid function. Fig. 3, an updating

of Fig. 5 of (7) shows how, by the year 2005, as battery technology improves, we can eventually move into the realm of all-electric, and zero emissions from the urban vehicles.

FUTURE OF THE USE OF PETROLEUM PRODUCTS IN AUTOMOBILES

What is going to happen to the 5.6 million barrels per day of motor gasoline consumed in the United States (8). What will this mean with respect to the projections that by the year 1990, the United States will be consuming some 26 million barrels of petroleum liquids per day?

Obviously, from Fig. 3, even with the HEBAH "in full swing" in 1985, the batteries will, at the 100 WH/lb level, account for only 1/4 of the vehicle's range. We will still need plenty of petroleum chemical products in the tank to operate the heat engine, be it a gas turbine, a steam engine, or a well-cleaned internal combustion engine.

What about 1995, when the batteries will be taking care of 3/4 of the range, and fuel for only 1/4 of the range is needed in a smaller fuel tank? There is nothing to worry about. Oil wells will still have to keep pumping, oil refineries refining, and the petrochemical industry producing liquid and gaseous fuels for burning. After all, the electric power for the charging of the batteries must come from someplace, and this will probably be a fossil fuel burning electric power generating plant. So, the oil well products now being burned in the car will be burned, and with lower overall air pollution and greater overall efficiency, in power stations. Refinery changes can be phased in slowly.

Despite all the great hopes for nuclear power generating stations, they still represent only a small fraction of the power generating capacity, and will not reduce the need for fossil fuel burning until substantially past the dates of Fig.3.

It is the consensus of many in the petroleum chemical industry field that the applications of petroleum products will be more and more for plastics and other end uses, and less in percentage for motive power. All studies show that plastics and other end uses, at present rates, are growing faster than the use in vehicular propulsion. The use in vehicular propulsion is approximately proportional to the number of vehicles, and this number is increasing with time. Actually, over the past decades, the use of petroleum products in vehicles has increased more than linearly with the number of vehicles, because the power per vehicle has been rising continuously. The horsepower level is definitely levelling out, both because of the automobile system reaching a point of maximum sensible utilization of power, and the increasing public and government pressure to reduce engine power in order to reduce the air pollution problem.

One of the potential major outlets for petroleum products in other than automotive use, but still geared to the "consumer", is in standby power for certain suburban applications where heavily

overloaded electrical power generation and distribution systems are projecting continuous heavy overloads for the next decades, with the incidents of power failures increasing. (Note: during the preparation of this paper, there were 4 power interruptions of over 1 hour duration in Westchester County, north of New York City).

With increasing affluence in our economy, the standby power system, operating from a heat engine-driven, petroleum fuel energized system, is considered by some to be economically feasible. A surprisingly viable presentation can be made for the overall system actually being cheaper than purchasing electricity from the local power generating station! As electrical power rates keep rising, due to the forces of increased labor costs, increased fuel costs and increased generating, transmission and distribution equipment costs, the alternatives seem attractive.

At present, the cost of high power semiconductors for guaranteeing "well behaved power" through inverters, etc., are high. However, all indications are that if a 10 kilowatt engine-generator system, with a standby battery for instantaneous take over of power, and high power semiconductors for inversion into accurately controlled voltage, frequency and waveform were mass produced, this could be a very acceptable item.

The noise associated with an internal combustion engine could be well muffled in the exhaust, and in a soundproof enclosure. The noise may be even less of a problem if the initial design revolves around a turbine type generator.

Therefore, when one sees all the possible future additional requirements for petroleum products, one might almost ask with concern "where will it all come from?".

The answer would be that as time goes by, and automotive vehicles use more and more electric power and less and less on-board petroleum based energy, there will be a switch over from gasoline to electric energy. This petroleum will be sorely needed for other products.

Therefore, I predict that the Petroleum Chemical Industry will look upon the electric car as a boon, rather than a bane. Just as the initial introduction of the dialling system in telephones was considered a threat, because of the displacement of workers, the dial system has proved to be a boon. If not for the dial system, it has been estimated that virtually all of the female working force in all industries in the United States would be required just to operate the telephones. The dial system eventually proved to be a great boon to labor, and the telephone system is hard pressed to obtain enough workers to do all the installation and necessary maintenance, and enough operators, even at the lower ratio of operators per call, to take care of the enormous increase in calls.

Is the electric car a threat? Hardly. It is a treat, and a treat that can be introduced via the bridge of the heat engine/battery hybrid vehicle over the next several decades. Everyone

should be encouraged to promote the development of electric vehicles, via more effective research in the field of higher energy density batteries. It will eventually redound to the benefit of the Petroleum Chemical Industry.

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(5) "Electronic Circuits for Speed Control and Braking", V. Wouk, Public Health Service Publication #99-AP-37,pp.123-142.

(6) "Electric Cars Will Greatly Reduce Air Pollution", Bradley Cozzens, IEEE International Conference on Communication, San Francisco, June 9, 1970.

(7) "Hybrid Power Systems for Vehicles", Hoffman, Public Health Service Publication # 999-AP-37, pp. 27-42

(8) Kerryn King - Private Communication to V. Wouk, May 11, 1970.

APPENDIX A

CALCULATIONS OF ELECTRICAL-POWER-GENERATING CAPACITY REQUIRED FOR INSTANT CONVERSION OF ALL HEAT ENGINE VEHICLES TO ELECTRIC DRIVE.

The following figures are based on approximate parameters in a region such as New York State, and are rounded off for ease of calculations.

(1) Assume number of vehicles = 10,000,000 = 10^7

This value is the correct order of magnitude for New York State.

(2) Assume engine horsepower per vehicle = 250.

A reasonable assumption; horsepower of buses and trucks is higher, and of many small cars, lower.

(3) From (2), engine kilowatts per vehicle = $250 \times 0.746 \cong 200$ kw

(4) Assume present electrical-power-generating capacity in New York State = 20,000,000 kw = 20×10^6 kilowatts.

This value is fairly close to the actual figure.

At first glance, it might appear as though the additional power required is indeed formidable. From (1) and (2), the additional capacity needed =

(5) 200 (kilowatts per vehicle) x 10^7 (vehicles) = 200×10^7 kw

From (4) and (5) the additional power generating capacity required is

(6) $(5) / (4) = 200 \times 10^7 / 20 \times 10^6 = 100$

i.e., the generating capacity would have to be increased 100-fold.

This figure looks formidable and has been quoted in newspapers; however, this reasoning incorporates two major fallacies.

FALLACY 1:

The 200-kilowatt power figure of equation (3) is <u>peak</u> power, used only infrequently, when the vehicle accelerates rapidly or moves up steep inclines. The <u>average</u> power required is substantially less.

Taking into account the lower average power requirement, plus the acknowledged greater efficiency of a battery-electric motor system, one might estimate the average power requirement at 20 kilowatts. So, from (6):

(7) $100 \times \dfrac{20 \text{ kw (average)}}{200 \text{ kw (peak)}} = 10$, or a tenfold increase.

The tenfold increase is still substantial.

should be encouraged to promote the development of electric vehicles, via more effective research in the field of higher energy density batteries. It will eventually redound to the benefit of the Petroleum Chemical Industry.

REFERENCES

(1) "The Automobile and Air Pollution: A Panel Study", 1968. Department of Health, Education and Welfare.

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FALLACY 2:

Vehicles are NOT used 24 hours a day. Considering values from almost 24 hours a day for some taxis, to 2 hours a week for some suburban cars, we can reasonably estimate an average use of 2.4 hours a day. Using (6) and (7) and 2.4 hours, we get

$$(8) \quad 100 \times \frac{20\ \text{kw}}{200\ \text{kw}} \times \frac{2.4\ \text{hr}}{24\ \text{hr}} = 1$$

i.e., the order of magnitude of increased electrical power required is a doubling, not a 100-fold, multiplication.

The recharging process for batteries is not distributed uniformly during the day. If we assume the worst, that all vehicles are plugged in at the same time and recharged in 8 hours, then the value in equation (8) would be tripled.

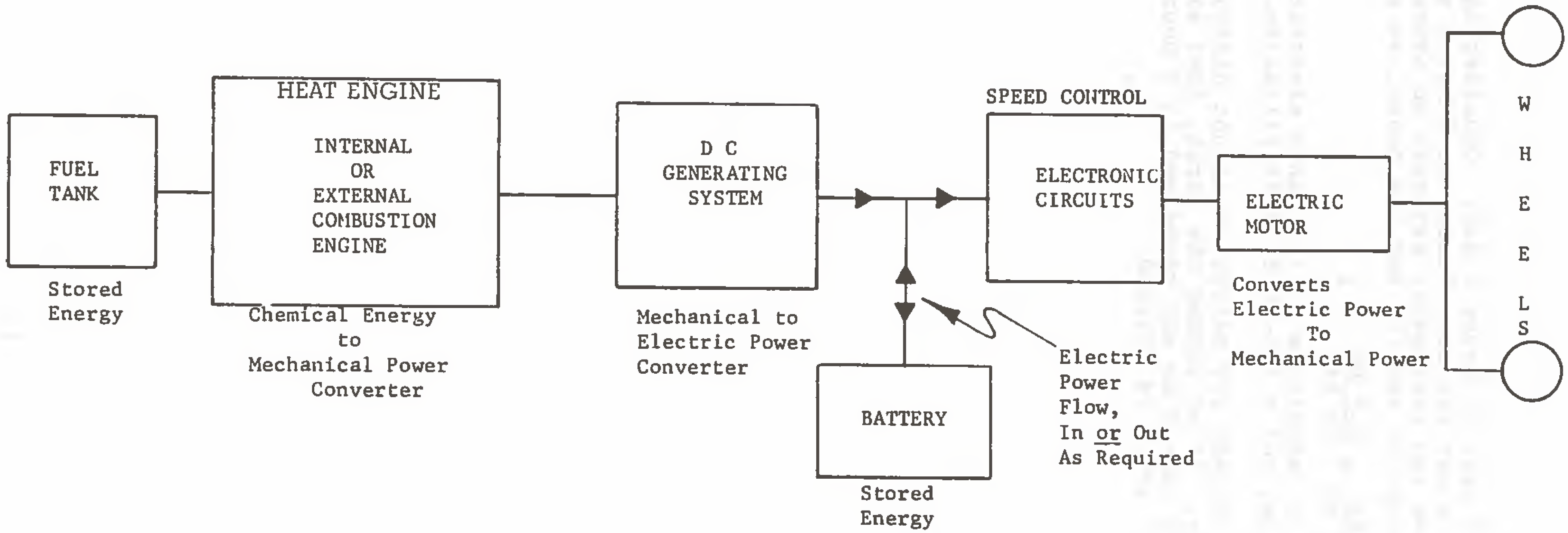


FIG. 1. BASIC SYSTEM, HEAT ENGINE/BATTERY HYBRID ELECTRIC

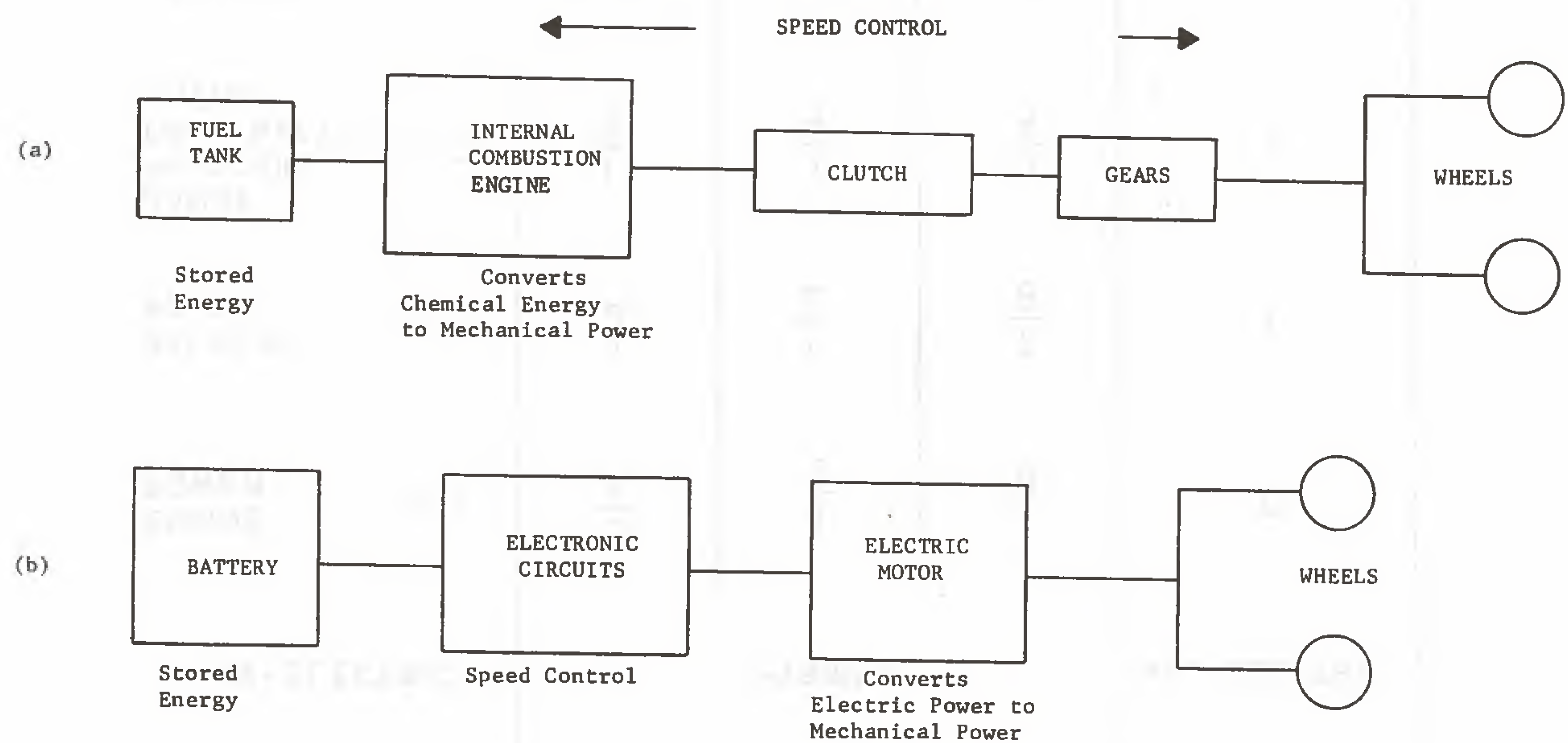
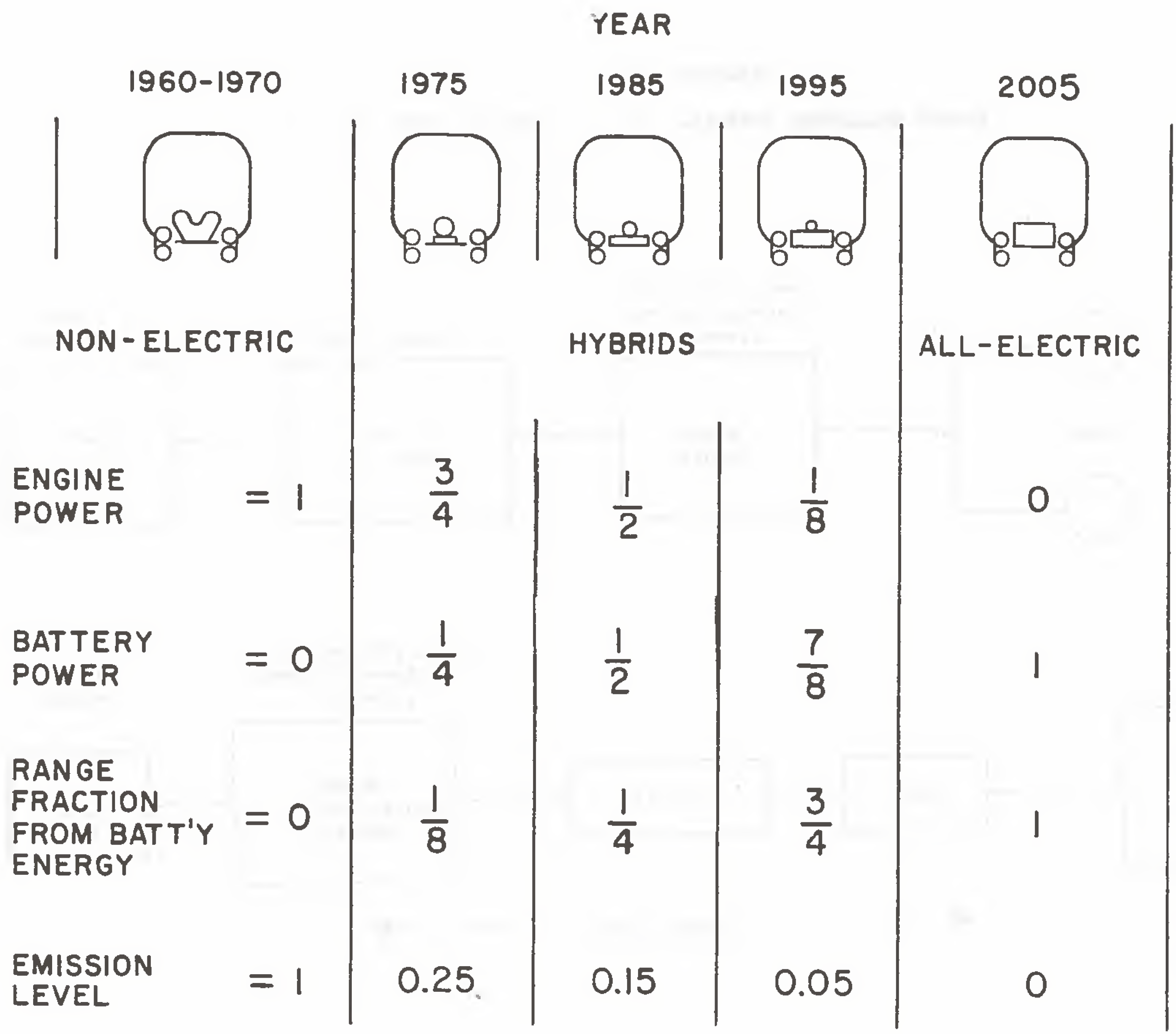


FIG. 2. BASIC SYSTEMS (a) INTERNAL COMBUSTION ENGINE

(b) ELECTRIC



REDUCTION OF ENGINE POWER REQUIREMENTS AS BATTERIES ARE IMPROVED OVER SEVERAL DECADES.

FIG. 3